ACTIVITY REPORT

May 2002

Natural Gas & Oil Technology Partnership

bringing department of energy national laboratories capabilities to the petroleum industry

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Note: Natural Gas and Oil Technology Partnership projects are reported according to the following schedule:

January, March, May, July, September, November	**February, April, June, August, October, December**
Oil and Gas Recovery Technology Drilling, Completion, and Stimulation Technology Diagnostic and Imaging Technology	Upstream Environmental Technology Downstream Environmental Technology Ultra-Clean Fuels Technology

Natural Gas and Oil Technology Partnership on the World Wide Web: http://www.sandia.gov/ngotp/

Drilling, Completion, and Stimulation Technology

Coiled Tubing Marking and Mark Recognition (Quality Tubing and INEEL)

Highlight:

- Project is complete.

Project is complete. The final report is complete and available from D.M. Weinberg at 208-526-4274 or weinbe@inel.gov.

Drill Cuttings Injection Field Experiment (BP Amoco, ChevronTexaco, Exxon, Gas Research Institute (GRI), Halliburton Energy Services, Hughes Christensen, MSD, Pinnacle Technologies, Schlumberger, Shell, and SNL)

No report received.

3D Analysis for Induction Logging in Horizontal Wells (BP Amoco, ChevronTexaco, Conoco, Electromagnetic Instruments, Exxon, Halliburton, Mobil, Phillips, Schlumberger-Doll, Shell, Unocal, Western Atlas, and SNL)

Highlight:

- The graphical user interface (GUI) transforms a user-entered 1D anisotropic model into a readable file for the 1D anisotropic forward modeling scheme.

A fully functional algorithm was developed to solve the 1D transversely isotropic electromagnetic (EM) inverse problem for the single-well case. The algorithm incorporates a quadratic solver and utilizes "Trust-Region" methods along with a re-weighted least-squares technique to constrain the ill-posed inverse problem. The inversion scheme is able to solve for all unknowns (assuming a 1D earth), which include layer dip and azimuth, horizontal and vertical conductivity, and layer boundaries. However, researchers are unable to invert for boundaries that deviate more than 10% from the true values. Techniques which can accurately estimate layer boundaries a priori to solving the inverse problem are being explored.

In addition to developing the inversion scheme, researchers tested the algorithm with several synthetic data sets to determine its limitations. Tests that determine the algorithm's capability of resolving layer thickness and conductivity were and continue to be conducted. Researchers also successfully inverted one field data set from the Schlumberger Test Well (data provided by EMI Inc.).

Project researchers presented the synthetic data results to Baker Atlas in Houston, TX and obtained another field data set from them. The Baker Atlas data is currently being processed.

Synthetic and real data inversions will be presented at two upcoming conferences: the 16th Annual EM Induction Workshop in Santa Fe, NM (June 2002) and the 72nd Annual SEG Meeting and International Exposition in Salt Lake City, UT (October, 2002).

The graphical user interface (GUI) being developed by the project now allows the user to input a 1D anisotropic model in terms of layer depths and resitivities, well trajectory, and the configuration of the induction tool, and correctly writes a file readable by the 1D anisotropic forward modeling scheme. This part of the project is currently on hiatus as the student who works on the GUI is working as a summer intern at BP. However, work will continue over the summer on developing a display for the results, and in the fall a 3D visualization package will be implemented that will allow for simultaneous viewing of all aspects of the model.

Downhole Seismic Source for Look-Ahead Pore Pressure Prediction While Drilling

(Halliburton, INEEL, and LBNL)

FY02 funding was received and FY02 budgets are in place. Planning meetings for field testing the sources in Oklahoma and Arkansas and a pre-deployment test series in Idaho are taking place in June. Field tests are likely to be conducted in July.

Acoustic Telemetry (MWD)

(ABB, Electroacoustics Research Laboratory, Extreme, and SNL)

No report received.

Development of Chemically Bonded Ceramic Borehole Sealants

(GPRI, ANL, and LANL)

Highlights:

- The thickening times of the CBPC sealants for offshore applications were studied.
- Development of lightweight sealants begins.

Project researchers studied the effect of simulated seawater on the setting behavior of the chemically bonded ceramic borehole sealants (CPBCs). Seawater was simulated by using 100 grams of specific salt composition to five liters of deionized water. The specific salt composition consisted of 77.76 g of sodium chloride (NaCl), 10.88 g of magnesium dichloride ($MgCl_2$), 4.74 g of magnesium sulfate ($MgSO_4$), 3.6 g of calcium sulfate ($CaSO_4$), 2.46 g of potassium sulfate (K_2SO_4), 0.22 g of magnesium bromide ($MgBr_2$), and 0.34 g of calcium carbonate ($CaCO_3$). The tap water used in previous experiments was replaced with this simulated seawater and placed in the consistometer to test the same compositions that were established for onshore applications. As usual, the thickening time was measured for a given composition such that it will give 70 Bc of consistency.

The tests conducted at 80°F, 150 °F, and 250 °F showed that seawater is gives more pumping time. For example, the composition developed for 80 °F has a thickening time of five hours with tap water. Researchers found that the thickening time was now more than six hours with seawater. To obtain a more adequate pumping time, researchers used accelerators to hasten the setting time, resulting in a time of 5 hrs and 50 min. Similarly, at 150 °F the pumping time with seawater was 7 hrs and 55 min, while the same with tap water was 2 hrs 58 min. At 250°F, the setting time with tap water was 3 hrs 50 min, but the same composition with seawater took over 6 hrs to set. Project researchers concluded that for offshore use of the formulations, it is necessary to accelerate these compositions.

The sealants developed by the project have a typical density of 1.8 g/cm^3, approximately 30% lighter than Portland cement. Density of the sealant can be reduced further by adding lightweight second-phase materials. Project researchers found that light cements of approximately 0.5 g/cm^3 can be produced, but their strength characteristics are poor. A formulation of 10%-reduced density was tested in the consistometer, and it gave a pumping time of four hrs and 35 min at 250 °F. Thus, it appears that it may be possible to develop formulations for lightweight cements with adequate pumping time for any depth. Detailed development will be conducted in the next period.

A field test of the CBPC sealants is being prepared. Researchers have met with some commercial partners and hope to develop a detailed plan.

Coiled-Tubing Deployed Microdrilling with Real-Time, Downhole Monitoring

(DeepLook, Phillips, and LANL)

Highlights:

- Equipment was installed to improve the mud cleaning system.
- The permit for 2002 Drilling Demonstration is in place.

The project received and installed the new 7-1/2 horsepower (HP) centrifugal pump on the mud-cleaning system to increase the velocity through the hydrocyclones and improve mud cleaner performance. This should increase both the volume of fluid cleaned and the fractions of solids removed, as well as reducing the average particle size removed. The components of the mud system were rearranged on the trailer to conform to general service administration (GSA) regulations.

Project researchers procured the bits, casing, a drilling motor, and water supply to support the first of two planned drilling campaigns in 2002. Project researchers will attempt to drill and complete an 800-ft deep well at the upper San Ysidro, NM site. Previous attempts to complete a deep well at this site were not successful, due to mud pump downtime, hole instability attributed to excessive downtime, and failed cementing procedures believed be related to hole instability. Hopefully, a short drilling effort and modified cementing procedures will allow a deep completion at this site.

In addition, project researchers will attempt to drill and complete a 600- to 800-ft-deep well through harder sedimentary formations below the 400-ft-thick volcanic tuff. If an aquifer is penetrated, researchers will attempt to demonstrate a prototype artificial lift system in a microwell.

Rocky Mountain Oilfield Testing Center (RMOTC) staff reviewed and approved a proposal to conduct a microdrilling demonstration at Teapot Dome. The proposal is for LANL to drill, complete, and produce several 600-ft-deep Shannon oil wells using the LANL coiled-tubing drill rig. The RMOTC field team will provide field support for drilling and completion of the wells, and evaluate the production potential of the wells produced. This proposal was submitted to DOE for consideration.

Effects of Well Conditions on Post-Perforation Permeability

(Halliburton, Penn State, and LLNL)

Highlights:

- Project researchers enhanced the ability of the flow model to simulate early time clean-up of the damaged zone by incorporating inertial and transient terms.

Previous code development focused upon the movement of fines within the rock and the influence this has upon permeability and post-shot productivity. Current efforts are aimed at simulating the cleanup of damaged rock immediately adjacent to the perforation. Cleanup of this damaged zone results from the transient pressure surge at a very early time. To investigate the early time evolution of pressure gradients through the damaged zone, project researchers enhanced the simulation capabilities to include inertial and transient terms. In addition, newly conducted experiments will provide additional data for testing the ability of the extended computational model to simulate both early time cleanup of damaged rock and the subsequent permeability-reducing deposition of fines.

Lifetime Performance Monitoring of Synthetic Fiber Mooring Ropes

(Petroleum Composites, Puget Sound Rope, Shell Global Solutions U.S.,Whitehill Manufacturing, and ORNL

Highlight:

- Initial test of integrated optical fiber-rope specimen shows good agreement between measured and applied strain values.

Tensile testing of rope specimens with integrated optical fibers began in this reporting period. Whitehill Manufacturing made a 35-m-long sample of four-strand rope with polymeric optical fibers integrated into two of the four strands. The ability of the fiber strain sensor to directly measure the applied strain in the rope is at issue in this testing phase. To evaluate this ability, a 75-cm-long segment of the integrated rope was strained in a tensile test machine while the strain was measured with the optical time-domain reflectometer and compared to the applied strain values. The initial test showed that the measured strain was in good agreement with the applied strain. Tensile tests will continue into the next reporting period.

In May, the project team presented a paper, "Direct Measurement of Large Strains in Synthetic Fiber Mooring Ropes Using Polymeric Optical Fibers", at the Offshore Technology Conference 2002 in Houston, Texas. This paper describes the sensor technology and details the progress to date on its development.

Disposable Fiber Optic Telemetry System for Use With Coiled Tubing

(GTI, CTES, and SNL)

No report received.

Automatic Flaw Detection and Identification for Coiled Tubing

(U of Tulsa, INEEL)

Highlight:

- INEEL attends TUCTMRC meeting.

INEEL personnel traveled to the University of Tulsa (U of Tulsa) to acquire additional signal analysis data. Data acquisition capabilities were transferred from the INEEL portable data acquisition to the U of Tulsa desktop system. Obtained data were used to check the effect of new equipment modifications on the quality of data acquired by the INEEL data acquisition system. The TUCTMRC modifications consisted of adding a gear reduction to the eddy current (EC) system drive motor to allow operation of the drive motor within its torque range, fabricating a coiled-tubing support fixture to stabilize and reduce friction in the system as the coiled tube is moved through the EC coil, and by redesigning the Hall effect probe mounting fixture to reduce variance in the stand-off distance between the Hall effect probe and the surface of the coiled-tubing surface.

Test data indicates that:

1. The speed of the coiled tubing through the EC coil is stable and constant.
2. The signal produced by the Hall effect probe from similar computed tomography (CT) surface defects showed different recognizable features. These different features show promise in being able to develop a computer algorithm to recognize different flaws.
3. Signal to noise ratios (with filtering) were acceptable.
4. Magnetic saturation in the material was not reached, thus indicating that the EC main coil must be operated at higher powers to eliminate any material difference on signal generation. As a result of these higher currents, additional cooling of the EC main coil will probably need to be implemented.

A literature search was initiated to look for information on EC flaw recognition and sizing using signal analysis techniques.

INEEL attended the TUCTMRC meeting. An overview of the INEEL program was presented to the consortium and informal discussions between INEEL and the U of Tulsa JIP consortium personnel were held regarding program collaboration. This information will be used to develop and prioritize tasks to meet specific milestones.

Laboratory Study on Borehole Stability and Sand Production in Weakly-Cemented Sand

(ChevronTexaco, Shell International, and LBNL)

Highlight:

- Kick-off meeting held with industry participants.

A kick-off meeting was held with the industry participants (ChevronTexaco and Shell International), and details of the originally planned experiments were discussed. Based on the feedback the researchers obtained from these discussions, first year goals were shifted from the establishment of laboratory-derived relationships between grain-scale properties and mesoscopic mechanical properties of weakly-cemented granular rocks to the identification of material properties and testing conditions (grain type, porosity, intergranular cohesion strength, and stress conditions) under which thin, sand-producing borehole breakouts are formed.

These borehole breakout tests will be performed using sodium silicate-cemented sand samples made using a technique developed at LBNL. The relationship between the grain-scale properties and the mesoscopic properties will be examined for the testing conditions of the interest and for the narrow range of test parameters. Project researchers are currently designing a testing system to perform biaxial compression tests on two-dimensional well bore analogues in thin slab samples. Preliminary results on weakly-cemented sand samples without confining stress in the plane-normal direction (parallel to the borehole and perpendicular to the slab surface) result in an unwanted splitting failure of the sample before a borehole breakout initiates. The design of the test frame will be modified so that controlled plane-normal stress or displacement can be applied to prevent this mode of failure.

Oil and Gas Recovery Technology

Improved Waterflooding Through Control of Brine Composition and Other Factors

(BP Amoco, U of Wyoming, and INEEL)

Highlight:

- Experimental work complete.

Experimental work at INEEL is complete and the final report is in preparation.

Fluid Identification Acoustic Logging Tool

(BP Amoco, CGG, ChevronTexaco, Conoco, Landmark Graphics, Schlumberger, Shell, Smedvig Unocal, Ward Petroleum, Western Atlas, and LANL)

No work was scheduled for this reporting period.

Measuring Sucker Rod Pump Parameters Downhole

(Harbison-Fischer, UT-Austin, and SNL)

Highlight:

- A pressure drop through the traveling valve was measured while pumping high viscosity fluid.

The pressure transducer for measuring compression chamber pressure downhole was proof-tested. Signal filters for the clear instrumented sucker-rod pump at UT-Austin were procured and a load cell for measuring the load below the polished rod was ordered. This new load cell, together with the existing load cell, allows direct measurement of stuffing box friction.

Measurement of the pressure drop across the traveling valve while pumping high viscosity oil has shown that, at the beginning of the upstroke, the ball does not fall under its own weight closing the valve. Instead, the valve closes by the rising of the seat and fluid flowing back into the compression chamber, sucking the ball into the seat. Thus, high viscosity oil causes delayed traveling valve closure even for a properly functioning sucker-rod pump.

Formation Logging Tools for Microboreholes (DeepLook, ChevronTexaco, and LANL)

No work was scheduled for this reporting period.

Coupled Geomechanical Deformation, Fluid Flow, and Seismic Modeling (Mobil, Schlumberger, UT-Austin, and SNL)

Highlight:

- Modifications were made to JAS3D to compute an element-based rock compressibility value.

Modifications were made to JAS3D to compute an element-based rock compressibility value. This rock compressibility value is computed for each element in the geomechanics model using rock constitutive model parameters. The element-based rock compressibility value will then be passed to IPARS where it will be used as part of an algorithm to adaptively control the frequency of data transfer between the flow simulator, IPARS, and the geomechanics code, JAS3D. The development and implementation of the adaptive time-stepping algorithm will be the focus for the next reporting period.

Semiautomatic System for Waterflood Surveillance (ChevronTexaco, Case Services, and LBNL)

Highlight:

- Two papers on spontaneous countercurrent imbibition and rock damage propagation were presented at 13th SPE/DOE Improved Oil Recovery. Symposium.

Daily field data are transferred to an LBNL computer via FTP connection. The software component providing processing and backup of the files now works in real-time mode. The control module of the program was encoded in C++. Now it is being tested, calibrated and debugged in automatic mode. The daily pressure set-point files are produced and transferred to the field operators in real-time.

Analysis of satellite images and rock damage assessment

Two papers (SPE75169 and SPE75230) on spontaneous countercurrent imbibition and rock damage propagation were presented at 13th SPE/DOE Improved Oil Recovery Symposium.

Mechanisms of Oil Recovery and Validation of Corefloods (ChevronTexaco, Phillips, and LBNL)

Highlight:

- Paper summarizing the development of the three-phase flow simulator presented at 13th SPE/DOE Improved Oil Recovery Symposium.

The development of the three-phase flow simulator continues. The results were summarized and presented at 13th SPE/DOE Improved Oil Recovery Symposium (paper SPE75193).

Pore network generation

A depositional model based on the distinct elements method was developed to simulate mechanical properties of sedimentary rocks. Various bond failure criteria were incorporated into the code to adequately simulate development of cracks from micro-defects and inhomogeneities of the medium. The results are in good agreement with laboratory experiments reported in the literature. The ability to understand and model rock damage propagation by development of systems of fractures at different length scales is extremely important for increasing oil and gas recovery from tight formations.

The work on synthetic rock generation by matching the correlation functions obtained from digital images of thin sections of real samples continues. The efficiency of the algorithms was dramatically increased by code optimization.

Direct Simulation of Near-Wellbore Mechanics

(ChevronTexaco, Halliburton, Schlumberger Shell, MIT, NMT, and SNL)

Highlight:

- Schlumberger joined ChevronTexaco, Halliburton, and Shell as an industry sponsor of the project with the execution of the amended project CRADA.

Schlumberger joined ChevronTexaco, Halliburton, and Shell as an industry sponsor of the project with the execution of the amended project CRADA. The project hired a postdoctoral researcher, Erik Strack, who will join the research group in September after completing his Ph.D. in Geotechnical Engineering. Two Ph.D. students, Dave Boutt from New Mexico Tech and the Scott Johnson from MIT, were also hired as graduate research interns, and have started familiarizing themselves with the formulation and implementation of the 2D code.

Current work is focused on the refinement and application of the 2D code, and the development of a non-spherical discrete element for the 3D code. The initial large-scale application of the 2D code will be the simulation of cavity formations in unconsolidated sands. In tightly packed models, unphysical flow blockages result from the 2D model idealization, preventing fluid from passing through the discrete-element assemblage. Project researchers circumvented this problem with the introduction of an "effective-geometry" concept, which reduces the footprint of the discrete-element geometries on the fluid mesh to create narrow flow channels through the 2D element assemblage.

In 3D, researchers have begun to research alternate, more realistic particle representations to the commonly used spherical discrete-element. At least one non-spherical, discrete element representation into the 3D DEM code later this year.

Finally, the project is still awaiting the formalization of the licensing agreement by the Sandia legal department, which will allow New Mexico Tech to begin beta testing the codes.

Project Publications

Cook, B.K., D.R. Noble, and J.R. Williams. "A Coupled DEM-LB Model for the Simulation of Particle-Fluid Systems", accepted for publication in the *Proceedings of the 3rd International Conference on Discrete Elements Methods*, Ed. Cook and Jensen. ASCE.

Cook, B.K., M.Y. Lee, A.A. DiGiovanni, D. R. Bronowski, E.D. Perkins, and J.R. Williams. "Discrete Element Modeling Applied to Laboratory Simulation of Near-Wellbore Mechanics", accepted for publication in the *International Journal of Geomechanics*.

Lee, M.Y., B. K. Cook, A.A. DiGiovanni, E.D. Perkins, and J.R. Williams, "Simulation of Borehole Failure Phenomena Using Discrete Element Modeling", *Eos Trans*. AGU, 82(47), T51A-0846, 2001.

Well Integrity Assurance for Sub-Salt and Near-Salt Deepwater GoM Reservoirs

(BHP, BP Amoco, ChevronTexaco, Conoco, ExxonMobil, Halliburton, Kerr-McGee, Phillips, Shell, and SNL)

Highlight:

- An alternative method of implementing pore pressure was developed.

Following discussions at the March 2002 Partners meeting, technical work focused on further refining and improving the reservoir-scale finite element modeling being performed with an idealized "pancake" geometry.

An alternative method of implementing pore pressure was developed so that this variable is defined on an elemental, rather than nodal basis. This approach eliminates numerical "bleeding" of pore pressure from the reservoir into the surrounding non-reservoir formations.

A systematic study of mesh convergence and tolerance is being conducted. The effect of the lateral extent of the model on the near-field results is also being evaluated systematically, as are the effects of rollered versus pinned lateral boundary conditions.

The current work is also extending the baseline analyses conducted with the pancake-geometry model to include (1) non-lithostatic initial states of stress

(including alternative methods for incorporating this); (2) transient salt creep; and (3) the effect of a stiff, and possibly creeping, basement layer. Also, development and analysis of additional idealized geometries were initiated.

Sandia staff visited BHP on May 7 and Shell E&P on May 8 to present work conducted under this project to company staff, and to discuss and identify key technical issues of interest to each company.

The nine industry partners were sent invoices for their Year 2 funding agreements with Sandia; Year 2 funding from four of the industry participants has cleared DOE/Sandia.

A manuscript submitted for publication in Oil & Gas Science and Technology was revised following peer review. The manuscript is currently in press.

Publications

J. T. Fredrich and A. F. Fossum, "Large-Scale Three-Dimensional Geomechanical Modeling of Reservoirs: Examples from California and the Deepwater Gulf of Mexico", *Oil & Gas Science and Technology - La Revue de l'IFP*, in press (2002).

An Integrated Approach to Assessing Seismic Stimulation

(Aera LLC, BP, ChevronTexaco, Conoco, Marathon, Phillips, Shell, ASR, Halliburton, OGCI, Piezo-Sona Tool, Schlumberger, UC Berkeley, LANL, LBNL)

The major goal of this partnership project is to obtain the comprehensive scientific and empirical knowledge needed to optimize reservoir stimulation for a wide range of field applications. LBNL and LANL have pursued this work for the past four years, with the main emphasis on laboratory work and initial theoretical work. This proposed effort, however, would be a more focused and balanced approach with increased emphasis on field validation and results. The field work is being performed at sites of application in a variety of geologic and reservoir conditions.

In March 2002, LBNL deployed a three-component (3-C) locking geophone at a 1750-ft depth in a well 43 ft from the stimulation well in the Lost Hills site. The source in the stimulation well was the ASR pulse source. The purpose of this test was to determine the source strength in order to design more comprehensive tests. The source puts out a pulse each stroke of the pump jack, about every ten seconds. Not knowing what to expect, researchers recorded the data on a 24-bit, wide-bandwidth recorder at a sampling rate of 0.5 ms. At the 43-ft source-receiver separation, the signals were clipped using the smallest gain. Therefore, researchers attenuated the signal by a factor of ten by means of a simple resistive network. The geophone was then moved up and down the well to determine signal strengths at different distances. The signal was lost when the geophone reached a downhole depth of 900 ft, 800 ft above the source. The observed signal displayed a strong 250-Hz ringing effect at all levels, well below the 2-kHz resonance frequency of the detectors. The ringing could either be the receiver-tool resonating or, more likely, the source well is ringing.

On the basis of the March test, researchers are currently designing the next test, which is to record in two wells simultaneously at different distances, one sensor in the close well (43 ft) and another sensor in a well between 500 and 1000 ft away. The sensors will be the same 3-C clamping tool used in the March tests, and the other sensor will be a newly acquired two level (2-m spacing) hydrophone. After researchers record a set of levels in each well, the tools will be switched and the measurements repeated. If the ringing is due to the sensor, this should be determined easily, if it is due to the source well ringing that should be apparent also. By stepping away from the source in the same horizon as the source, researchers will be able to measure the attenuation and signal strength in the reservoir horizon, thus providing input to the numerical modeling effort.

Theory and Numerical Modeling

The UC Berkeley research team investigated the natural frequencies of a cylindrical porous medium without interstitial fluids. Natural frequencies were determined theoretically and estimated numerically. The natural frequencies of loose sand range from 146 Hz to 311 Hz. A diffusion equation and a Laplace equation whose dependent variables are two different linear combinations of fluid pressure and total dilatational stress were derived previously. Based on those equations, the pore pressure distribution, porosity change, and increment of fluid content subject to specific initial and boundary conditions corresponding to a fluid pressure-pulsing experiment at the laboratory scale were calculated for a porous medium containing one fluid. Numerical stimulation is being performed to investigate whether resonance behavior exists and could effectively stimulate fluid flow rates.

Advances in Water Resources accepted a manuscript, based on the project model of coupled two-phase fluid flows in porous media, for publication.

Laboratory Experiments

With the arrival of new-start project funds in May 2002, LANL researchers made preparations for the next set of laboratory core-flow stimulation experiments. Laboratory apparatus is being refurbished and calibrated. Formation core samples will be obtained from several producing sites that are currently being stimulated and monitored under the field portion of the project. Initial lab experiments will investigate stress stimulation effects on single-phase permeability caused by disruption of pore fluid boundary films. The same samples will then be tested during 2-phase flow to obtain a better understanding of altered wettability mechanisms. Various improvements to the existing flow measurement systems are being implemented to allow better control and characterization of critical 2-phase flow and dynamic stress parameters.

Diagnostic and Imaging Technology

Advanced Sensor Technology for Microborehole and Other Seismic Instrumentation

(Input/Output, Philips, and LANL)

Highlights:

- A downhole sonde was built and deployed for side-by-side tests of accelerometers.
- A test bed was built to compare sensors.
- New downhole platform to test input/output (I/O) sensors are being designed.

A downhole sonde was built for side-by-side testing of one vertical component input/output (I/O) accelerometer and one vertical component Wilcoxon accelerometer. The unit was deployed downhole but exhibited problems, due to a bad trace on the flex circuit board. The unit was rebuilt and will be redeployed at the earliest opportunity. In the meantime, a test bed was built; it uses a shaker to compare the various sensors in a laboratory setting. The test platform is built on a 1600-lb piece of granite isolated from the building. It is still much noisier then the downhole environment, but will be a very useful tool.

A new sensor from I/O was received and installed on the test bed and is being compared to the older model I/O accelerometer and the Wilcoxon accelerometer, along with a larger commercially available accelerometer. In addition, a new downhole platform is being designed so that the new I/O sensor can be tested downhole.

Improvements were also made to field test setup. A new sensor was designed and built to give a more reliable “Time Zero” from the accelerated weight-drop seismic source.

Large Downhole Seismic Sensor Arrays

(ChevronTexaco, Conoco, Exxon, OYO Geospace, Shell, U of Arkansas, and INEEL)

Highlight:

- Project is complete.

Project is complete. The final report is complete and available from D.M. Weinberg at 208-526-4274 or weinbe@inel.gov.

Improved Prestack Kirchhoff Migration for Complex Structures

(Conoco, Cray/SGI, Golden Geophysical, Kerr-McGee, Shell, and LANL)

No work was scheduled for this reporting period.

Inversion of Full Waveform Seismic Data for 3D Elastic Parameters

(Amerada Hess, ChevronTexaco, Conoco, Fairfield Industries, GX Technology, Marathon, Unocal, and SNL)

No report received.

High-Speed 3D Hybrid Elastic Seismic Modeling

(Burlington Resources, GX Technology, and LBNL)

Highlight:

- Instructions and documentation for Framework are complete.

The project effort was dedicated to concluding the project. The instructions and documentation for Framework, the MPI-standard-based C++ Framework Wave, a computer program which takes care of parallelization of FORTRAN-based codes written for single CPU versions of finite-difference applications are completed. Framework handles 2D and 3D applications of various kinds and is based on use of BOXLib library, which works both for PC clusters and parallel supercomputers. Framework provides support for heterogeneous work-loads, parallel load-balance and data distribution. It also handles both center-based and staggered-grid algorithms with cell-centered and grid-node-centered parameter arrays.

Next-Generation Seismic Modeling and Imaging

(Advanced Data Solutions, Anadarko, BHP Petroleum, BP Amoco, ChevronTexaco, Conoco, Core Laboratories/Tomoseis, ExxonMobil, Fairfield Industries, Marathon, Mitchell Energy, Paradigm Geophysical, PGS-Tensor, Phillips, Shell, Society of Exploration Geophysicists [SEG], Unocal, Veritas DGC, Western Geophysical, Stanford, U of Houston, LANL, and LLNL)

Highlight:

- Project researchers develop a method to perform residual prestack migration of P-S data that can be applied after wave-equation prestack migration.

Working with industry participants, project researchers defined model parameters for testing the feasibility of performing very large acoustic and elastic 3D simulations through a new industry-defined subsalt geologic model. The model is about 18 km by 28 km horizontally, and 10 km deep. The test simulations will use a central frequency of 15 hz. These numerical simulations will require up to 1 TeraByte of internal memory on massively parallel computers.

The project also made progress in developing and testing velocity estimation algorithms for both P data and P-S (converted wave) data. Project researchers developed a method to perform residual prestack migration of P-S data that can be applied after wave-equation prestack migration. This prestack residual migration can correct for both the misfocusing of the image and the lateral mis-imaging of P-S wave conversion points that result from an inaccurate migration velocity.

Rapid Imaging of Interwell Fluid Saturations using Seismic and Multiphase Production Data

(BP Amoco, ChevronTexaco, JNOC, Landmark, Phillips, RC2, Statoil, Tomoseis, Total-Fina-Elf, Texas A&M, and LBNL)

Project researchers continue work on the computation of sensitivities of seismic amplitudes to changes in reservoir parameters, such as porosity and permeability. An analytic approach for computing sensitivities was compared to a purely numerical calculation. This analytic approach, which is orders of magnitude faster than the numerical method, gives equivalent results. The analytic sensitivity computations were incorporated into the seismic amplitude inversion code.

A more accurate method for computing reflections from a stack of thin layers was implemented as well. The method is an invariant imbedding scheme which is quite efficient and accurate. The invariant imbedding approach allows for tuning effects and attenuation. The subroutine was included in the amplitude inversion code.

A preliminary test of the integrated watercut and amplitude inversion code is complete. Both watercut arrival time and amplitude change errors were reduced by approximately an order of magnitude. Project researchers are in the process of applying the method to time-lapse seismic data from a Gulf of Mexico field.

Offshore Oil Field Characterization with EM Methods

(SNL)

No report received.

Innovative Wave-Equation Migration

(Advanced Data Solutions, Amerada-Hess, Applied Geophysics Services, Baker Atlas, BHP, Conoco, Exxon-Mobil, Fairfield Industries, GX Technology, Petroleum GeoServices, Phillips, Screen Imaging, Shell, TomoSeis, Unocal, Veritas DGC, and LANL)

Project researchers investigated using the wave-path migration scheme to determine a migration aperture for each common-shot gather, and to apply this aperture into wave-equation migration. There are two advantages to use such an aperture in wave-equation migration. First, researchers determine reference slownesses used in wave-equation migration from within the migration aperture rather than from the entire model for a given extrapolation interval. This can reduce the perturbation levels within the migration aperture and increase migration accuracy. Second, researchers migrate a common-shot gather into a migration aperture determined using the wave-path migration scheme that is very efficient. This can reduce migration artifacts and can give a correct weight for each image point during amplitude-preserving migration. This idea was tested using a synthetic dataset for a 2D slide of the SEG/EAGE salt model. Researchers obtained more accurate and better quality images compared to those obtained using conventional wave-equation migration schemes.

Testing and Validation of High-Resolution Fluid Imaging In Real Time

(Deeplook, KMS Technologies, KJT Enterprises, LBNL, and SNL)

No report received.

Autonomous Monitoring of Production

(Aera Energy, ChevronTexaco, SteamTech Environmental Services, TomoSeis, and LLNL)

Highlight:

- A second set of field casing surveys were successfully conducted at the Vacuum field.

Using results from the baseline survey combined with laboratory results, a second set of field casing surveys were successfully conducted at the Vacuum field in May. The initial survey was conducted using the same measurement protocol as was used in the original, baseline dataset. For these measurements, the wells were disconnected from surface electrical and piping. Additional datasets were obtained using improved, symmetric measurement schedules, which are designed to produce more balanced measurements across the well pattern. These datasets will constitute a new baseline for reference for future surveys.

A key question to address is the safety of personnel and equipment during active measurements when the well casings are connected to surface piping and electrical. A series of measurements were designed to test the potentials generated when well casings are used as current electrodes during measurement. After the initial datasets were obtained, the wells were re-connected to surface electrical and piping. All the pumping and injection operations returned to normal usage. Within the well pattern, working hardware included submersible pumps and rod and rocker pumps as well as water injection. A series of measurements were made to ensure safe operations for both personnel and equipment as power was applied to individual well pairs. Touch potentials remained well within safe ranges, even when full power was applied. No adverse changes were detected on the equipment lines.

The key datasets were repeated, with all wells connected to surface piping and electrical. Data quality "connected" versus "disconnected" was compared to determine the signal degradation due to pumping and electrical effects. Field analysis indicates signal to noise degradation to be within tolerable limits. Analysis of these results continues.

Carbon dioxide (CO_2) injection, which was planned for the main well pattern, was postponed in the central wells in the original pattern over which these surveys were conducted. During the intervening seven months, these wells were used for a water flood. Analysis of the processed data will focus on the detection of changes consistent with water flood.

CO_2 is being injected into the wells immediately adjacent to the original well pattern. Project researchers extended the range of the casing survey and collected additional data including two wells used for the CO_2 flood. These measurements were obtained with all wells connected and operating under normal conditions as well. Analysis of the processed data will focus on detection of changes consistent with CO_2 migration.

Project researchers successfully field-tested the autonomous control system in the field. The control computer was connected to the field acquisition system via a 1000-ft telephone cable. A separate laptop computer was used to call the control computer, successfully initiating a data acquisition sequence. This is the first step toward remote operations. For normal operations, it seems likely that a cell link will be preferred, as increasing the length of telephone line linking to a land base eventually limits signal strength.

Anisotropic Properties of Compacting Clay-Rich Rocks

(LBNL)

Highlight:

- Principal investigators meet with industry representatives.

The project commenced with a meeting between the principal investigators (PI's) from LBNL and industry representatives from BP, Shell, Corelabs, and Conoco. Feedback on the proposed approach for measuring the VTI elastic constants of a compacting clay-rich rock and loading/pore pressure protocols was provided. Suggestions regarding frequency scaling issues and alternative laboratory approaches for measuring elastic constants were provided, and were incorporated into the research plan.

Three-inch geotechnical core from a deepwater field in the Gulf of Mexico was provided by Chevron. Exploratory ultrasonic tests were performed on one of these cores under ambient (no confining stress) and approximately uniaxial strain loading conditions (0-2.4 MPa). Ultrasonic tests in the 1-2.5 MHz range showed clear P-wave transmitted waves through a 1-cm thick sample. S-waves, however, were strongly attenuated, and could not be clearly identified. Because the loading rate for these tests was high (approximately 50 psi/min), additional tests will be conducted with slower loading protocols using a new consolidation cell with larger areas for pore fluid drainage. The primary objective of these follow-up tests will be to determine the stress level, sample thickness, and frequency required for observable ultrasonic S-waves. These values will have direct impact on the geometry of the consolidation cell and the properties of the ultrasonic phased arrays.

Two approaches for measuring the VTI elastic constants of a compacting clay-rich rock sample are currently being analyzed. The first approach follows that given in the project proposal and consists of an instrumented consolidation cell with phased P- and S-wave source arrays housed within one of the loading platens and point P- and S-wave transducers parallel and perpendicular to the loading axis. In this configuration, the 5 elastic constants are extracted by a series of P- and S-wave ultrasonic measurements made with point transducers perpendicular to the loading axis, and phased P- and S-plane waves parallel and at oblique angles to the loading axis. Pending the outcome of the S-wave attenuation tests described above, the S-wave phased array may be eliminated, and the S-wave transmission measurements replaced with S-wave reflection measurements off the cell wall-clay interface.

The second approach will attempt to make the VTI elastic constant measurements in the 10-50 kHz range using near sonic frequency resonance. While researchers have performed resonance ultrasonic spectroscopy (RUS) measurements of the VTI elastic constants of rocks under ambient conditions, the problem of performing such measurements on clay-rich rocks under uniaxial strain loading presents a number of problems, such as spectral broadening due to the large attenuation of clay, and the effects of the loading vessel on the resonance modes. Project researchers are currently exploring the possibility of developing a consolidation vessel containing piezoelectric actuators for multiple point excitations. In principle, the actuator array can be used to excite individual resonance modes by replicating the mode shape. This may allow more robust estimation of the elastic constants in situations where spectral broadening (due to high attenuation) in combination with high mode density causes smoothing of the resonance spectrum. An update on this effort and the efforts described above will be provided in the next bi-monthly report.

Realistic Velocity Anisotropic Estimation in Complex 3D Environments

(LBNL)

Highlight:

- Project begins.

The project began in May 2002. A kick-off meeting was held in Houston with representative from BP, Chevron, Conoco, Kerr McGee, Phillips and Tomo-Seis in late March to set the agenda for the project in the first year. A number of representative models were defined and the contribution from each sponsoring company was agreed upon.

Initial work concentrated on validating the 2D and 3D codes against other codes and analytic solutions. Run times and accuracy were improved. A new code for tilted transversely anisotropic media based on the Eikonal equations was developed as a check with the finite difference codes. In addition, a new pseudo-spectral code was developed as an additional check. Work has begun running specific models defined by the sponsors and estimating anisotropy parameters using traditional methods.

Partnership Office

The first industry review for the new Gas Issues Technology Area was held May 30, 2002, in Houston, TX. Fourteen industry reviewers representing both the drilling and storage aspects of natural gas reviewed 14 project proposals. The results and prioritization of this review will be developed in June. The partnership thanks John Rogers of NETL and Norm Goldstein of LBNL for pulling together a highly successful review at short notice.

Norm Goldstein returns as the partnership co-chair and LBNL representative as Mike Hoversten returns to his busy tasks as PI on several new partnership projects. We thank Mike for running the Oil and Gas Recovery Technology Area during FY2002.

With the completion of review and project selection for the new Gas Issues Technology Area, the partnership closes the review cycle for FY2002.

Depending on DOE re-scoping of the fossil energy program and congressional funding, the partnership is poised to reload and start the solicitation of new proposals and subsequent industry review and prioritization for FY2003, starting in August.